Ontario

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Materials Engineering and Research Office Report

# Qualitative Assessment of Aggregate for Presence of Clay

MERO-016

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| **Abstract** | The presence of clay in aggregate has significant impact on the performance of concrete, asphalt mixes and granular bases. Two different test procedures are currently used in the industry to determine the presence of clay in aggregates. The Ontario Provincial Standard Specification (OPSS) uses a test method that was developed for clayey soils (the Atterberg limit tests). The Association of American State Highway and Transportation Officials (AASHTO) recommends the methylene blue adsorption method, which is a titration technique that is widely used in the oil industry to check the drilling fluid.<br><br>The intent of this study is to investigate the effectiveness of the current OPSS standard and the test methods employed to determine the presence of clays in aggregates, and to recommend a test method that is effective, simple, inexpensive, and easy to perform.<br><br>The study concludes that a modified version of the test method currently used by OPSS is the most effective and inexpensive way to assess the aggregates for presence of clay, and that the titration technique recommended by AASHTO is questionable. |
| **Key Words** | Adsorption, aggregate, Atterberg limits, methylene blue, clay, activity, liquid limit, plastic limit, plasticity index |
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# Executive Summary

The performance of hot-mix asphalt, concrete and granular base may be significantly influenced by the presence of harmful clays and organic impurities in aggregates. In engineering practice, the amount of clays or plastic fines in aggregate is restricted by specifying the physical and index properties of the fine-grained portion of the aggregate. Ontario Provincial Standard Specification (OPSS) 1010 requires that the aggregate used in base and sub-base be non-plastic based on the liquid and plastic limits (Atterberg limits) determined from tests that were developed for clayey soils.

Liquid and plastic limits are the upper and lower limits of plasticity of clays. The plasticity index or plastic range of a soil is the range of water content within which a soil possesses plasticity. The Atterberg limits are based on the concept that the clayey soils can exist in any of four states, i.e., solid, semi-solid, plastic and liquid, depending on the water content. Both liquid and plastic limit tests are required to be performed on material passing 0.425 mm. In the case of aggregates, the test sample may contain a substantial quantity of fine sand and the test procedure may not be effective in detecting the plastic fines or clay in aggregates. In addition, the Atterberg limit tests require a considerable amount of sample preparation work and a skilled technician.

In recent years, the methylene blue adsorption test has been used to obtain information on the presence of clay minerals in soils and rocks as well as to determine the properties of clay minerals. This test method is essentially a titration technique employed to determine the amount of methylene blue solution adsorbed by a suspension of particles smaller than 75µm.

The intent of this study was to develop a test method that is effective, simple, inexpensive and easy to perform in the field. The plastic limit test (modified version) and the methylene blue adsorption technique are examined to see if they were suitable to replace the test procedure currently specified in OPSS 1010 to determine the presence of clay. The plastic limit determined from the material finer than 75µm (modified version) is recommended for the qualitative assessment of aggregates that contain harmful clays. The test procedure recommended is inexpensive, effective and easy to perform in the field.

The qualitative assessment of aggregate by Atterberg limits and the effectiveness of this test method to determine the presence of clays are covered in Chapter 2. Chapter 3 describes the theoretical background of methylene blue adsorption and a summary of this test method. Test data and analyses are provided in Chapters 4 (Atterberg limits) and 5 (methylene blue adsorption). Chapter 6 provides a summary and discussion of the test results. The proposed test method to determine the presence of clay in aggregate is presented as Appendix A. The test record is provided in Appendix B.

# 1. Introduction

The presence of harmful clays and organic impurities in aggregates has significant impact on the performance of asphalt paving mixes, concrete and granular bases. In specifications, the amount of harmful clays in aggregates is restricted by specifying the requirements for physical and index properties of the fine-grained portion, i.e., silt and clay size particles, of the aggregate. Ontario Provincial Standard Specification (OPSS) 1010 requires that the aggregates used in base and sub-base be non-plastic, i.e., plasticity index equal to zero, determined on the basis of liquid and plastic limit tests that were developed for soils.

The presence of clay or plastic fines in the finer portion of the aggregate may induce stripping in hot mix asphalt paving mixtures. Excessive plastic fines in the aggregate may also cause problems such as stability and rutting of pavements, flushing during placing of hot mix asphalt, and in some cases stiffening of the asphalt binder in the hot mix, which leads to fatigue cracking. The granular base must be free draining, but the presence of clay can cause reduction in the permeability of the granular base. This may lead to failure of the pavement structure due to frost penetration and weakening of the base.

The current OPSS to assess the aggregates for presence of harmful clays is based on the plasticity index determined on material passing the 0.425 mm (425μm) sieve, which may contain a substantial quantity of fine sand. Plasticity index determined from the Atterberg limit tests may not be effective to detect the presence of plastic fines in aggregates, especially when the aggregates contain clay lumps and a very small quantity of clay minerals. In view of this, a test method that is effective, simple, inexpensive and easy to perform in the field needs to be developed to assess the quality of aggregates used in highway construction.

The plasticity index is the difference between the liquid limit and plastic limit determined on material passing the 0.425 mm sieve. Liquid and plastic limits are known as Atterberg limits, which were originally developed for clayey soils. Determination of liquid limit requires a considerable amount of sample preparation work (especially for aggregates), testing equipment and a skilled technician to perform the test. The plastic limit test does not require any expensive equipment, but the test is somewhat more arbitrary and requires some practice to get consistent and reproducible results.

The methylene blue adsorption test has been used in recent years to obtain information on the presence and properties of clay minerals in soils and rocks. This test method is essentially a titration technique employed to determine the amount of methylene blue adsorbed by a suspension of fines, i.e., particles smaller than 75 μm. The American Association of State Highway and Transportation Officials (AASHTO) has developed a provisional test method, TP57-99, based on this technique to determine the harmful fine material (including clay and organic impurities) present in an aggregate. This test method also provides a relationship

between the methylene blue value and expected performance of hot mix asphalt pavement as related to moisture susceptibility. However, this test procedure is being reviewed for its effectiveness to assess aggregates containing clay lumps.

Test method C 837-99, developed by the American Society for Testing and Materials (ASTM), covers the procedure for measuring the adsorption of methylene blue by clay. In this test method, the adsorption value is reported as methylene blue index. However, this test procedure is being revised to address several deficiencies.

All together, four aggregate samples that were likely to contain plastic fines or clay were tested for this study. The samples were collected from one pit and three quarries located in the Province of Ontario. Some of these pits and quarries are actively producing aggregates. MTO has been using aggregates produced from some of them for highway construction.

This report presents the results of a study undertaken to investigate the effectiveness of Atterberg limit tests (MTO LS-703/704) to determine the presence of harmful clays in aggregates and to examine the possibility of substituting methylene blue adsorption value for plasticity index in OPSS 1010. The report recommends a modified plastic limit test procedure to assess the suitability of an aggregate that contains harmful clays. The proposed test method is appended to this report.

# 2. Assessment of Aggregate by Atterberg Limits

## 2.1 GENERAL

The Atterberg limits are based on the concept that clayey soils can exist in any of four states, i.e., solid, semi-solid, plastic and liquid, depending on the water content. The water contents that correspond to the boundaries between the states of consistency are termed shrinkage limit, plastic limit and liquid limit. The Atterberg limits for the fine-grained soils are related to the amount of water that is attracted to or adsorbed on the surface of the soil particles. The amount of adsorbed water is largely influenced by the amount of clay and the type of clay mineral that is present in the soil.

Adsorbed water is the layer of water molecules that are held round a clay mineral particle by hydrogen bonding and by attraction to the negatively charged surfaces. It is different from the absorbed water and cannot be removed by oven drying at 110° C. The absorbed water is the water that is absorbed by the pore spaces in the aggregate or soil and not so tightly held on to the surfaces. It is similar to hygroscopic moisture and can be removed by oven drying, but not by air drying.

In geotechnical engineering practice, the liquid limit and plastic limit are used for soils classification purposes, and to correlate with the engineering properties and engineering behaviour of fine-grained soils. In addition, the Atterberg limits provide information as useful, at least from an engineering point of view, as the more sophisticated x-ray diffraction and differential thermal analysis to identify predominant clay minerals present in fine-grained materials.

## 2.2 LIQUID LIMIT

The liquid limit is the lower limit of viscous flow (the liquid state). It is defined as the moisture content at which the soil sample changes from a plastic state to a liquid state. A standard mechanical device developed and standardized by Casagrande (1948) is used in North America to determine the liquid limit of soils.

Complete details of the liquid limit apparatus and the test procedures are given in ASTM D 4318 and AASHTO T89. The liquid limit in both of these test methods is defined as the water content at which a standard groove cut in a remoulded soil sample placed in a metal cup will close over a distance of 13 mm at 25 blows of the cup falling 10 mm on a hard rubber or micarta plastic base.

The liquid limit is related to the amount of water that is adsorbed on the surfaces of the fine-grained material. It may be expected that the amount of attracted or adsorbed water will be largely influenced by the amount of clay, and also the type of clay, that is present in the material, because of the great increase in surface area per unit mass (specific surface) with decreasing particle size. It was pointed out by Rosenqvist (1957) that the liquid limit of clays depends mainly upon three factors:

1. The amount and nature of the minerals;
2. The degree of electro-chemical saturation; and
3. The polarizability of the adsorbed ions.

## 2.3 PLASTIC LIMIT

The plastic limit is the lower limit of the plastic state. It is the water content at which the soil begins to crumble when rolled out into a 3 mm diameter thread. Goldschmidt (1926) concluded that the clay properties, mainly the plasticity, are dependent upon both the crystal chemistry of the mineral phase and the atomic structure of the liquid phase.

The plastic limit test is not complicated to perform and requires a ground glass plate, sieve and auxiliary equipment such as spatula, plastic or porcelain storage container, water bottle, washing pan, scale and oven. This test method does not require any calibration of the equipment or skill to perform, but it requires some practice to produce consistent and reproducible results. Complete details of the test procedure are given in ASTM D 4318 and AASHTO T90.

## 2.4 PLASTICITY INDEX

The range of water content within which a soil possesses plasticity is known as the plastic range. The numerical difference between the liquid limit (LL) and plastic limit (PL) is the plasticity index (PI), which is a measure of the plastic range.

$$PI = LL - PL$$

## 2.5 ACTIVITY VALUES FOR IDENTIFICATION OF CLAY MINERALS

The presence of even a small amount of clay minerals in a soil mass can markedly affect the engineering properties of that mass. As the amount of clay increases, the behaviour of the mass is increasingly governed by the clay mineral present in the mass. Skempton (1953) defined a quantity called activity, A, to correlate plasticity index and percentage of clay (particle size < 2μm), based on the reasoning that the amount of adsorbed water will be largely

influenced by the amount of clay that is present in the soil.

$$A = (PI)/(\% \text{ of Clay})$$

Figure 2.1a shows activity values for various clayey soils, and Figure 2.1b shows activity values for three basic clay minerals, i.e., kaolinite, illite and montmorillonite (Skempton 1953). Clays with an activity value around one ($0.75 < A < 1.25$) are classified as normal (e.g., illlite, 0.5 to 1.3), and clays with a lower value ($A<0.75$, e.g., kaolinite, 0.3 to 0.5) are classified as inactive. Clays with a higher value ($A>1.25$, e.g., montmorillonite, 1.5 to 7.2) are classified as active. The activity is an indication of the colloidal properties of clay, and is mainly dependent on the content and type of clay minerals and organic colloids as well as on the electrolyte content of the pore water (Skempton, 1953).

The Plasticity Index versus Liquid Limit chart shown in Figure 2.2 provides information to determine the predominant clay mineral present in a soil sample. Simply locating the sample in question on the chart and comparing its location with those of known minerals determines the clay mineral. The glacial lake clays from around the Great Lakes region in Canada are predominantly illite, and plot right above the A-line.

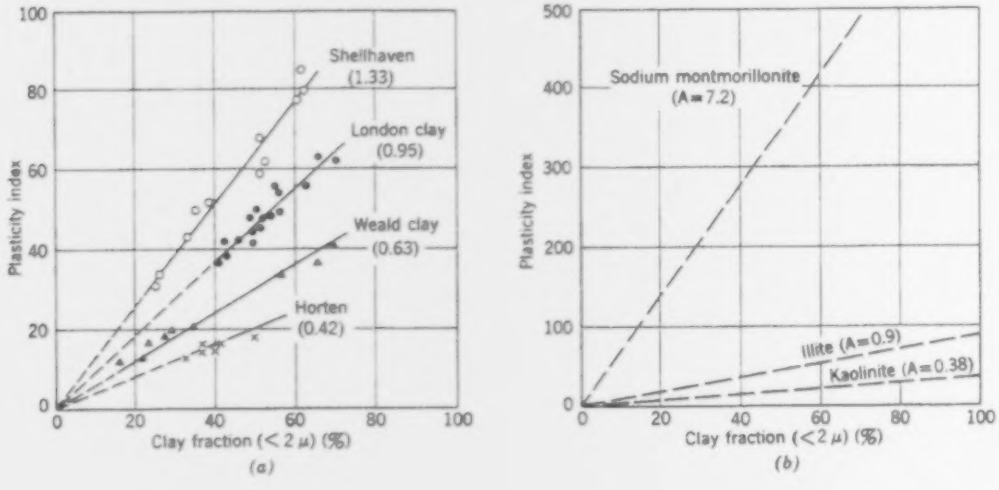


**Figure 2.1 Relationship between Plasticity Index and Clay Fraction (Skempton 1953)**

## 2.6 EFFECTS OF DRY SAMPLE PREPARATION ON ATTERBERG LIMITS

It is customary and a requirement by most of the test methods (ASTM D 4318, AASHTO T89 and BS1377: 1990) to report the method of preparation of the sample with the test results. BS1377: 1990 requires that the soil not be allowed to become dry for its definitive methods of testing. Head (1992) reported that even partial drying by exposure to air at laboratory temperature can cause changes in the physical behaviour of some soils, especially tropical residual soils, which can result in dramatic changes in their plasticity properties. Some of these changes are not reversible when the soil is re-mixed with water. These changes not only affect the index properties, but also result in changes in the particle size distribution due to aggregations of fine particles forming strongly bonded larger particles.

Where possible the samples used for liquid and plastic limit determination should not be dried before testing. In practice earth fill or base and sub-base materials are not dried in a manner similar to the procedures followed in a laboratory environment before placement. If the aggregates are assessed based on Atterberg limits, the use of samples in their natural state, where possible, or a wet preparation procedure for removal of particles retained on the 425μm sieve, should be specified.

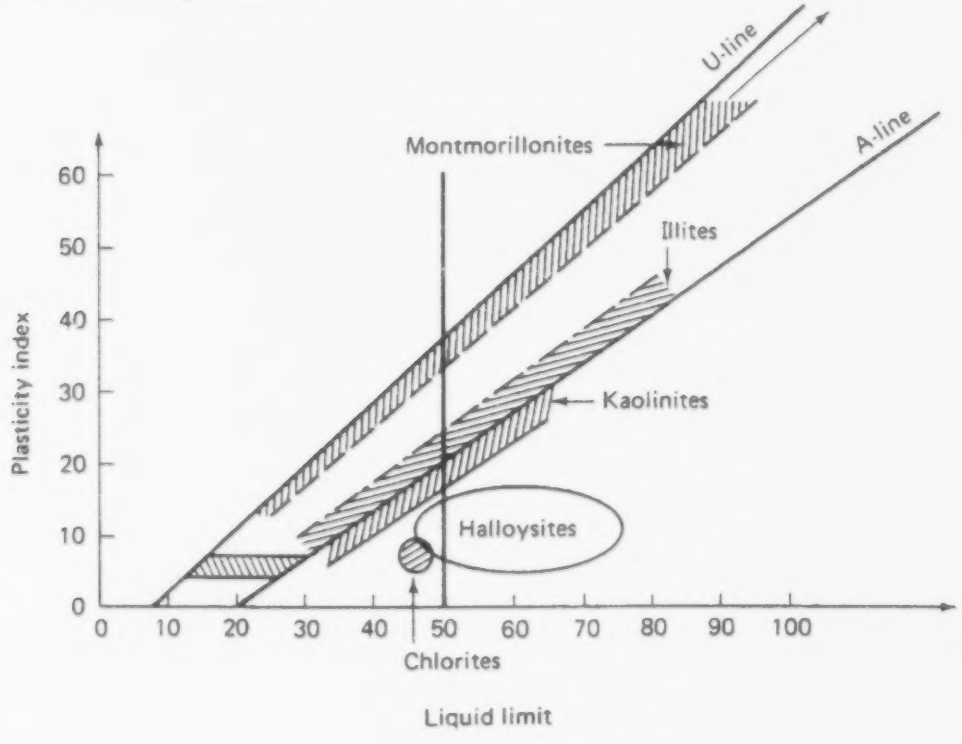


**Figure 2.2 Locations of Common Clay Minerals on Plasticity Chart**

## 2.7 EFFECTIVENESS OF CURRENT SPECIFICATION TO DETERMINE PRESENCE OF CLAYS

The OPSS 1010 requirement is that the aggregates must be non-plastic, as determined in accordance with MTO LS-703 and 704. In addition, the amount of material passing 75μm should not exceed 8% of the total mass, with the exception of quarried bedrock aggregate where a maximum of 10% is permitted. The plasticity index requirement that is specified in OPSS 1010 is an index property of the material finer than 425 μm, and provides only a qualitative assessment of the aggregate.

The preparation of samples received from the field for all the aggregate tests, including determination of plasticity index, is done in accordance with the procedures described in MTO LS-600. This method requires that the samples be brought to a free flowing condition by drying at 110 ± 5° C. It may completely destroy or alter the plastic properties of materials passing the 75μm sieve (silt and clay), and may result in negligible or no plastic fines. To conform to the requirements of testing for Atterberg limits, a portion of the sample should be split before oven drying and this reserved portion is used for liquid and plastic limit tests.

At present, the liquid and plastic limits, which are used to compute the plasticity index, are determined using material passing the 425μm sieve. In the case of aggregate, the material passing the 425μm sieve will usually contain a very large proportion of fine-grained (75μm to 425μm) sand and very little clay, which may result in classifying the material as non-plastic, since the sand and silt sized particles make up the bulk of the test sample.

# 3. Assessment of Aggregate by Methylene Blue Solution

## 3.1 GENERAL

In recent years, the methylene blue adsorption test has become a popular method to obtain information on the presence of clay minerals in soils and rocks. The test procedure was first described by Fairbairn and Robertson (1957). Several methods, such as hydrophilic and cation exchange, were in use to measure the adsorption of methylene blue. Some of these methods are quite involved and complicated, and did not gain widespread acceptance.

The theory is that when a methylene blue solution is added to a water and clay mix, the positive methylene blue ion will drive away the positive ions of the clay mineral. This process will continue until all the other positive ions are expelled and up to this point, all the methylene blue will attach to the clay surfaces. There is a distinct point in this process where the clay minerals become electro neutral. After this point, the clay mix can no longer absorb methylene blue and the remaining methylene blue ions will stay in the solution.

The "spot method" developed by Jones (1964) is essentially a titration technique which determines the amount of methylene blue adsorbed by a suspension of fines. This method is widely used in the oil industry to check the quality of drilling mud (bentonite slurry). In recent years, this method has been applied to both soils and rocks. The Laboratoire Central des Ponts et Chaussées (LCPC) investigated this method since the late 1970s over a fifteen year period, and concluded that it is a convenient way to obtain information on the nature and activity of clay minerals in soil and rock.

ASTM (Vol. 15.02) and AASHTO (Provisional Standards) have published the methylene blue adsorption method in their standards. ASTM recommends this method (ASTM C 837-99) as a test procedure to differentiate mineral fillers (which do not contain clay, being finely ground rock) and plastic fines in an aggregate. However, it has not been accepted as a Full Standard by AASHTO, but has been included as a Provisional Standard to determine the amount of potentially harmful fine materials, including clay and organics, in an aggregate. The Task Force, which is responsible for maintaining and updating AASHTO TP57-99, is currently reviewing this test procedure for its effectiveness to assess aggregates containing clay lumps. Kandhal *et al* (1998) concluded that the methylene blue adsorption test is the best test method to indicate the presence of plastic fines that may induce stripping in hot mix asphalt paving mixtures. The relationship between the methylene blue value (MBV) and expected performance of hot mix asphalt pavement as related to moisture susceptibility provided in AASHTO TP57-99 is as follows:

| Methylene Blue Value (mg/g) | Expected Performance |
|---|---|
| ≤ 6 | Excellent |
| 7 – 12 | Marginally Acceptable |
| 13 – 19 | Problems/Possible Failure |
| ≥ 20 | Failure |

The methylene blue value is the amount of MB that can be adsorbed by the sample. A high MB value indicates the presence of high amount of clay and vice versa.

## 3.2 THEORETICAL BACKGROUND

Clay minerals are tiny colloidal-sized layered crystalline substances evolved primarily from chemical weathering of certain rock forming minerals. Chemically, clay minerals are hydrous silicates of aluminium and other metallic ions. There are only two fundamental crystal sheets, silica (tetrahedral) and alumina (octahedral). The way in which these sheets are stacked, together with different bonding and metallic ions in the crystal lattice, differentiates clay minerals such as kaolinite, illite and montmorillonite.

The studies conducted by Hang and Brindley (1970) showed that clay suspensions start to flocculate at a specific concentration of methylene blue. This point was interpreted as the amount of methylene blue needed to cover the surfaces of the clay particles with the methylene blue cations. The methylene blue adsorption value basically expresses the quantity of methylene blue solution required to cover the total surface of the colloidal-sized particles in the sample with a monomolecular layer of methylene blue. It may be assumed that the MBV is proportional to the colloidal content of the sample multiplied by the specific surface of the colloidal-sized particles. MBV is calculated in milligrams of solution per gram of material passing the 75μm sieve as follows:

$$MBV = (CV)/W$$

where MBV = Methylene Blue Adsorption Value in mg of solution per g of material passing the 75μm sieve
C = Concentration of methylene blue solution (mg/ml)
V = Amount of methylene blue solution adsorbed or required for titration (ml)
W = Mass of material passing the 75μm sieve in grams

Typical methylene blue adsorption values published by Verhoef (1992) for three major clay types are given in Table 3.1.

**Table 3.1 Typical Range of MBV for Common Clay Minerals**

| Clay Mineral | MBV (g/100 g) | MBV (mg/g) |
|---|---|---|
| Kaolinite | 2 - 5 | 20 – 50 |
| Illite | 5 -15 | 50 – 150 |
| Montmorillonite | 15 - 40 | 150 - 400 |

## 3.3 SUMMARY OF TEST PROCEDURE

The methylene blue test for this study was carried out in accordance with the AASHTO Provisional Standard. Details of the test method, including significance and use, are given in AASHTO TP57-99. A summary of the test method follows.

A representative sample of the material to be tested is dried to a constant mass at 110 ± 5° C and sieved through a 75 µm sieve. A slurry consisting of 10 grams of fine-grained material passing the 75 µm sieve and 30 ml of distilled water is prepared. Methylene blue solution with a concentration of 5mg/ml is titrated into the slurry. After stirring, a drop of the slurry and methylene blue mix is removed using a glass rod and placed on filter paper. A blue ring around the drop is formed on the filter paper when the sample can no longer absorb more methylene blue. Once the end point is reached, the volume of the methylene blue solution used is noted and the MBV is computed.

# 4. Atterberg Limits and Particle Size Analysis Test Data

## 4.1 SOURCE OF AGGREGATE SAMPLES

Aggregate samples collected from one pit and three quarries located in the Province of Ontario (see below) were tested for this study. MTO has been using aggregates produced from some of these pits and quarries for several years for highway construction.

## 4.2 SAMPLE PREPARATION

The samples from the field were dried a room temperature to a free flowing condition and each sample was divided into two equal portions using a splitter. One of the portions from each site was further divided into four equal amounts of representative samples and collected in four containers numbered 1 to 4. The second portion from each site was retained for complementary tests and verification purposes.

The total mass of sample from each of the four containers was recorded. Then the sample from container No. 1 was separated into two portions by sieving through a 425μm sieve. The portion of the material retained on the 425μm sieve was further broken down by using a rubber-covered pestle and was again sieved through the 425μm sieve. The sample from container No. 1 was separated into particles coarser and finer than 425μm.

After the second sieving, the material retained on the 425μm sieve was washed until the wash water was clear and dried to a constant mass at 110 ± 5° C, and its mass was determined. The percentage of material passing the 425μm sieve was determined by subtracting the mass of particles coarser than 425μm from the total mass of the sample. The portion of the material passing the 425μm sieve was divided into two representative samples for Atterberg limit tests and hydrometer analysis. The sample preparation process described above was repeated for the samples in containers No. 2 to 4 using 150μm, 106μm and 75μm sieves, respectively. The purpose of separating samples on different size sieve openings was to obtain test specimens with varying percentages of clay sized particles, i.e., particles finer than 2μm.

## 4.3 ATTERBERG LIMITS

The liquid and plastic limits of all four samples, i.e., materials finer than 425μm, 150μm, 106μm and 75μm, respectively, were determined in accordance with the procedures described in ASTM D 4318-00, Method A (Multi-point Method). A motorised Casagrande apparatus

fitted with a revolution counter was employed for the liquid limit test. As required by the test method, approximately 150 grams of test specimens from each sample were prepared by adding distilled water. The test specimens were left over-night to reach moisture equilibrium, and to obtain a uniform distribution of water throughout the specimens. The liquid limit, plastic limit and plasticity index determined for all four fractions are given in Tables 4.1 to 4.4 (see below).

## 4.4 PARTICLE SIZE ANALYSIS

Particle size analysis was performed on all four samples to determine the percentage of clay in each fraction (passing 425μm, 150μm, 106μm and 75μm sieves). The tests were carried out in accordance with MTO LS-702. This test method is a modified version of ASTM D 422-98. In MTO LS-702 (Revision 19, 2001), the floating depth of the hydrometer in the soil suspension is calculated using the physical properties of the hydrometer and the cylinder. In addition, the test method requires that the specific gravity of the sample tested be determined. The specific gravity of the solids is required in this test procedure to compute the specific gravity correction factor α, and the constant K to determine the particle diameter corresponding to each elapsed time.

The percentage of clay in each fraction was computed from the hydrometer test results. In addition, the percentage of clay in the aggregate sample was computed based on the particle size analysis results and the masses recorded during sample preparation described in Section 4.2. The results for all four fractions are given in Tables 4.1 to 4.4 (see below).

## 4.5 WALKER BROTHERS QUARRY, VINELAND (N03-023)

### 4.5.1 Quarry Location and Geology

The aggregate sample tested was Quarried Granular "A" from Walker Brothers quarry. This quarry is located near the edge of the Niagara Escarpment south of Vineland in the Town of Lincoln, Regional Municipality of Niagara. It exposes a 16 m section of the Lockport Formation, consisting of 5.5 m of the Gasport Member (thin to massive bedded medium crystalline dolostone) underlying 10.5 m of the Goat Island Member (massive bedded fine crystalline dolostone containing nodules of chert and gypsum).

### 4.5.2 Test Results and Analyses

The results are presented in Table 4.1 and in the form of a plot in Figure 4.1, and show a much greater increase in liquid limit value per percent increase in the clay content (1.18) than plastic limit (0.15). The rate of increase in liquid limit is almost eight times that of plastic limit. The aggregate sample contains only 2.2 to 2.3% of clay, but the test results of the four fractions indicate that the fines from the aggregate are plastic.

**Table 4.1 Test Results for Samples from Walker Brothers Quarry, Vineland**

| Passing Sieve Size | Plasticity Properties | | | % Of Clay (<2μm) | | Activity (A) (PI)/ %Clay |
|---|---|---|---|---|---|---|
| | Liquid Limit | Plastic Limit | Plasticity Index (PI) | Fraction | Aggregate Sample | |
| 425μm | 18.6 | 16.7 | 1.9 | 13.2 | 2.3 | 0.14 |
| 150μm | 20.8 | 16.9 | 3.9 | 15.0 | 2.2 | 0.26 |
| 106μm | 22.0 | 16.9 | 5.1 | 16.1 | 2.2 | 0.32 |
| 75μm | 23.6 | 17.4 | 6.2 | 17.4 | 2.3 | 0.35 |

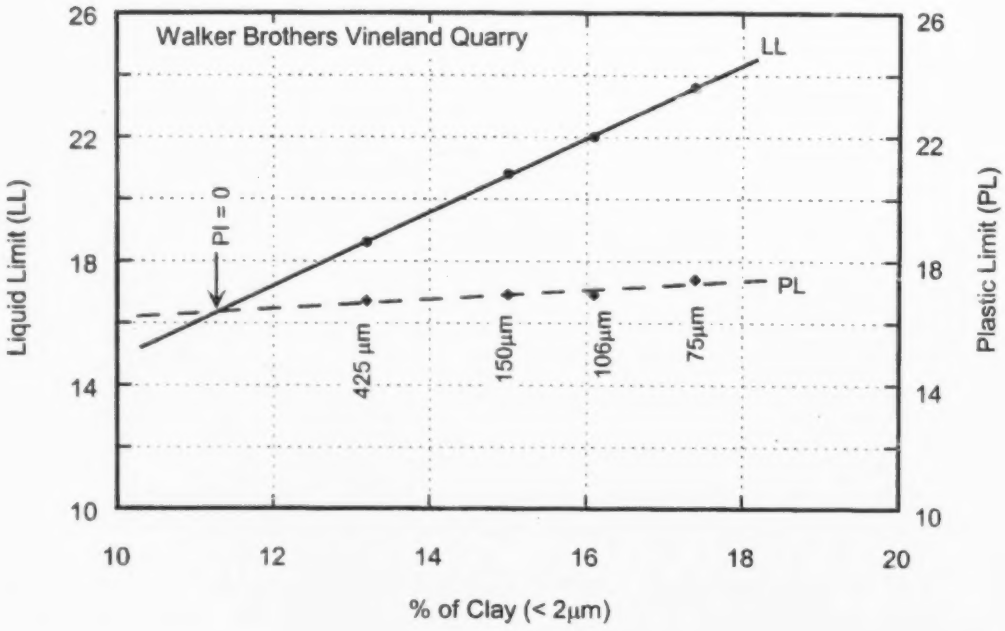


**Figure 4.1 Relationship Between Atterberg Limits and Clay Fraction**

The activity values computed from the plasticity index and the percentage of particles finer than 2μm range from 0.14 to 0.35. The activity value of 0.35, corresponding to material finer than 75μm, suggests that the predominant clay mineral present in the aggregate fines is kaolinite (0.3 to 0.5). However, the peak locations from an x-ray diffraction test performed on material finer than 75μm (see Section 5.4) do not agree with the findings from activity values, and suggest the predominant clay mineral is illite. The difference in the test results is discussed further in Section 6.

## 4.6 SUNSHINE PIT, THUNDER BAY (S20-059)

### 4.6.1 Pit Location and Geology

The Sunshine pit is located west of Thunder Bay on Highway 102 near Kaministikwia River. The bedrock and gravels of this area are composed of extensively metamorphosed mafic metavolcanic, metasedimentary and felsic intrusive rocks. Glaciofluvial outwash was deposited in this area along the course of the ancient Kaministikwia River meltwater channel that emptied into the Lake Superior basin.

The outwash had its origin at the Dog Lake Moraine 17 km north of the Sunshine Pit. Outwash gravel deposits near this pit are veneered by glacial lake red clay. The clay layer in some locations exceeds depths of 10 m, and the clay may also be found as boulders associated with the outwash gravels. This clay has resulted in repeated failures of granular materials on highway contracts in this area. When the amount of clay is excessive the granular material becomes relatively impermeable, which results in a poorly drained and low strength pavement layer. This seriously reduces the pavement life. In some cases failures have occurred within a few hours (Rogers *et al*, 1995).

### 4.6.2 Test Results and Analyses

The test results are presented in Table 4.2 and also provided in the form of a plot in Figure 4.2. The material finer than 425µm did not contain an adequate amount of clay for the Atterberg limit tests to be performed. The fines from this fraction are classified as non-plastic (NP). The increase in the liquid limit per one percent increase in clay content is 0.35, indicating a low specific surface area for water to access, and the rate of increase in plastic limit is only 0.10. The sample of Granular 'A" tested contains only 1.0 to 1.1% of clay, but the test results of the three fractions indicate that the fines from the aggregate are slightly plastic.

**Table 4.2 Test Results for Samples from Sunshine Pit, Thunder Bay**

| Passing Sieve Size | Plasticity Properties | | | % Of Clay (<2µm) | | Activity (A) (PI)/ %Clay |
|---|---|---|---|---|---|---|
| | Liquid Limit | Plastic Limit | Plasticity Index | Fraction | Aggregate Sample | |
| 425µm | NP | NP | NP | 7.8 | 1.0 | NP |
| 150µm | 27.1 | 26.5 | 0.6 | 14.6 | 1.1 | 0.04 |
| 106µm | 28.1 | 26.8 | 1.3 | 21.6 | 1.1 | 0.06 |
| 75µm | 30.9 | 27.6 | 3.3 | 22.5 | 1.0 | 0.15 |

*Note: NP = Non Plastic, Atterberg limit tests could not be performed.*

The computed activity values are low, ranging from 0.04 to 0.15, suggesting that the aggregate fines are deficient in clay minerals even though the percentage of particles finer than 2μm ranges from 14.6% to 22.5%. The peak locations from an x-ray diffraction test performed on material finer than 75μm (see Section 5.4) did not show any clay minerals.

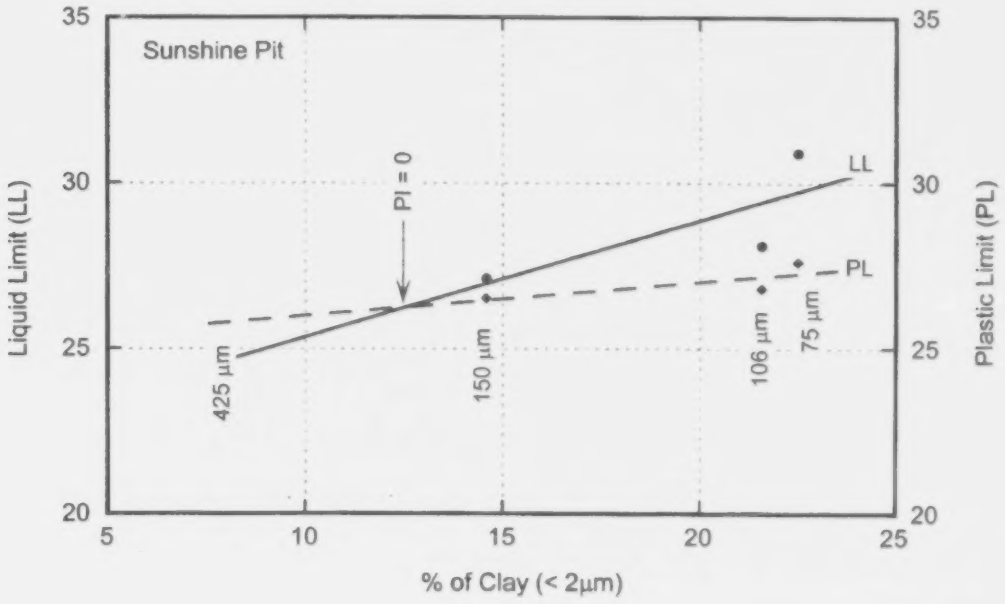


**Figure 4.2 Relationship Between Atterberg Limits and Clay Fraction**

## 4.7 WALKER BROTHERS QUARRY, THOROLD (N03-018)

### 4.7.1 Quarry Location and Geology

This quarry is located on the brow of the Niagara Escarpment in the City of Thorold, Regional Municipality of Niagara. It exposes a 12 m section of the Lockport Formation, consisting of 6 m of the Gasport Member (thin to massive bedded medium crystalline dolostone) underlying 6 m of the Goat Island Member (massive bedded fine crystalline dolostone containing gypsum nodules). The sample tested was quarried Granular "A".

### 4.7.2 Test Results and Analyses

The test results are presented in Table 4.3 and in the form of a plot in Figure 4.3. The liquid limit increases at a rate of 0.65 with increase in the clay content, but the rate of increase in the plastic limit over the same range is only 0.18. The aggregate from this source contains only 2.3 to 2.4% of clay. However, the test results of the four fractions indicate that the fines from the aggregate are plastic.

The fines from the four fractions contain a considerable amount of particles finer than 2µm (16.0% to 24.5%), but the computed activity values range from 0.11 to 0.24. This indicates that the colloidal portions of the fines are deficient in clay minerals. In this case, the type of clay mineral present cannot be concluded from the activity values.

**Table 4.3 Test Results for Samples from Walker Brothers Quarry, Thorold**

| Passing Sieve Size | Plasticity Properties | | | % Of Clay (<2µm) | | Activity (A) |
|---|---|---|---|---|---|---|
| | Liquid Limit | Plastic Limit | Plasticity Index | Fraction | Aggregate Sample | (PI)/ %Clay |
| 425µm | 18.0 | 16.2 | 1.8 | 16.0 | 2.4 | 0.11 |
| 150µm | 21.4 | 16.5 | 4.9 | 20.2 | 2.3 | 0.24 |
| 106µm | 22.3 | 17.2 | 5.1 | 21.0 | 2.3 | 0.24 |
| 75µm | 23.4 | 17.7 | 5.7 | 24.5 | 2.4 | 0.23 |

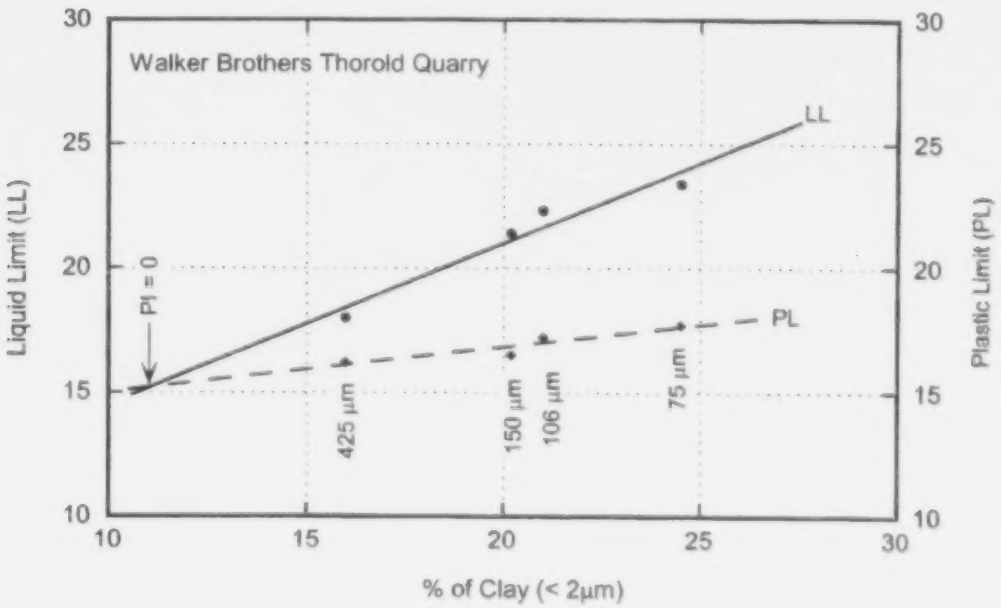


**Figure 4.3 Relationship Between Atterberg Limits and Clay Fraction**

## 4.8 VINEMOUNT QUARRY, STONEY CREEK (G08-011)

### 4.8.1 Quarry Location and Geology

This quarry is located 4 km south of Winona in the City of Stoney Creek, Regional Municipality of Hamilton-Wentworth. The quarry exposes a 19.5 m section of the Lockport Formation, consisting of 15.3 m of the Goat Island Member underlying 4.2 m of the Eramosa Member. The Goat Island Member is thin to medium bedded, and consists of fine to medium crystalline dolostone with interbedded shale in the upper part (the Vinemount shale beds); gypsum nodules and chert nodules and beds are common, chert being particularly abundant in a 2.4 m thickness (the Ancaster chert beds). The Eramosa Member is thin bedded, and consists of fine to medium crystalline dolostone.

### 4.8.2 Test Results and Analyses

The results are presented in Table 4.4 and in the form of a plot in Figure 4.4. In a manner similar to the samples from the other sources, the liquid limit (rate of increase 0.48) and plasticity index increase with increase in the percentage of particles finer than 2μm. As noted in the previous cases with similar geological setting, the increase in the plastic limit over the range of samples tested is insignificant and the rate of increase is only 0.09. The sample contains only 1.9 to 2.1% of clay, but the Atterberg limit test results of the four fractions indicate that the fines from the aggregate are plastic.

**Table 4.4 Test Results for Samples from Vinemount Quarry, Stoney Creek**

| Passing Sieve Size | Plasticity Properties | | | % Of Clay (<2μm) | | Activity (A) (PI)/ %Clay |
|---|---|---|---|---|---|---|
| | Liquid Limit | Plastic Limit | Plasticity Index | Fraction | Aggregate Sample | |
| 425μm | 20.2 | 16.9 | 3.3 | 18.0 | 1.9 | 0.18 |
| 150μm | 22.7 | 17.4 | 5.3 | 21.3 | 2.0 | 0.25 |
| 106μm | 22.6 | 17.7 | 4.9 | 22.6 | 1.9 | 0.22 |
| 75μm | 24.0 | 17.6 | 6.4 | 25.7 | 2.1 | 0.25 |

The Atterberg limit and hydrometer test results of the sample from this quarry are almost identical to those for the Vineland and Thorold quarries. The fines from Vinemount aggregate contain a significant amount of material finer than 2μm, but the activity values (0.18 to 0.25) are considerably lower than the values established for clay minerals such as kaolinite (0.3 to 0.5). The low activity values do not provide conclusive evidence for the type of clay mineral present in the aggregate fines. This may be due to the presence of non-clay fines in the fraction finer than 2μm composed of rock fragments such as calcite, silica and gypsum.

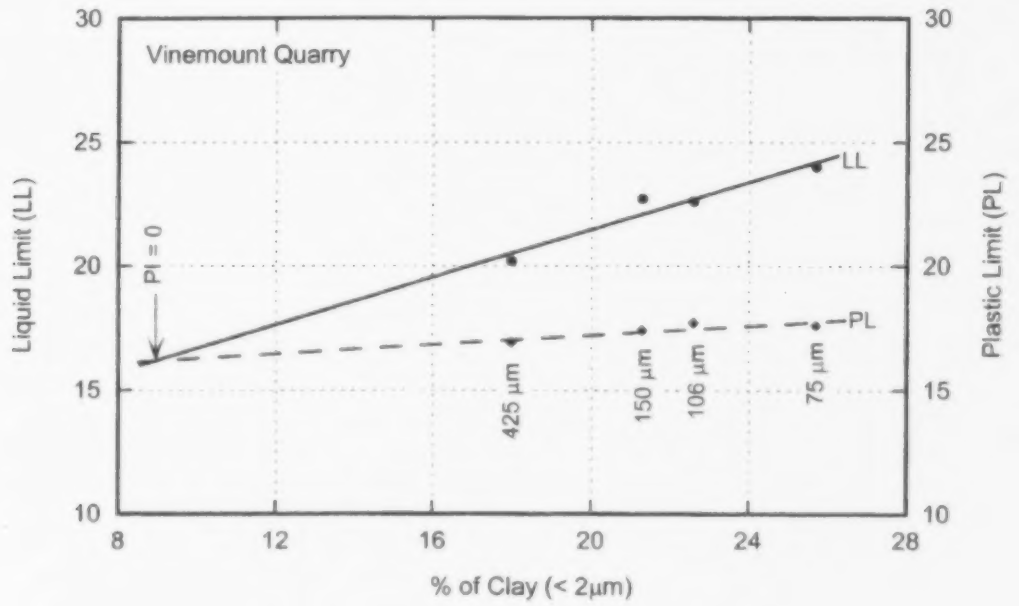


**Figure 4.4 Relationship Between Atterberg Limits and Clay Fraction**

## 4.10 EFFECTS OF CLAY CONTENT ON THE PLASTIC LIMIT

The specific surface area accessible to water increases with an increase in clay content. As a result, the plastic limit is expected to increase with the increase in clay content. In contrast, the results of the Atterberg limit tests performed on the aggregate samples indicate that the plastic limit is almost constant (the rate of increase ranges from 0.09 to 0.18) within the range of clay fractions tested. It appears that the plastic limit depends only on the predominant clay mineral and is not influenced by the amount of clay. The effect of clay content on the plastic limit was further investigated by testing samples prepared by mixing commercially available silica sand (Ottawa sand) and kaolinite (Kaolex BN, LL = 88.6 & PL = 38.6) in different proportions.

The Ottawa sand used in this study is composed of crystalline silica (quartz), manufactured by U. S. Silica Company of Berkeley Springs, West Virginia, USA. The silica sand was mechanically ground to particles finer than 75μm and mixed with kaolinite. The chemical composition and other related information for kaolinite are given in Table 5.1. Four samples containing mixtures of silica sand and kaolinite were prepared. The proportions of Ottawa sand and Kaolex BN in each sample and the methylene blue adsorption values are given in Table 4.5. The results are also provided in the form of a plot in Figure 4.5.

**Table 4.5 Plastic Limit Results for Silica Sand and Kaolinite Mixes**

| Sample No. | Silica Sand (%) | Kaolinite (%) | Plastic Limit |
|---|---|---|---|
| 1 | 80 | 20 | 18.7 |
| 2 | 60 | 40 | 18.2 |
| 3 | 40 | 60 | 24.6 |
| 4 | 20 | 80 | 30.5 |
| 5 | 0 | 100 | 38.6 |

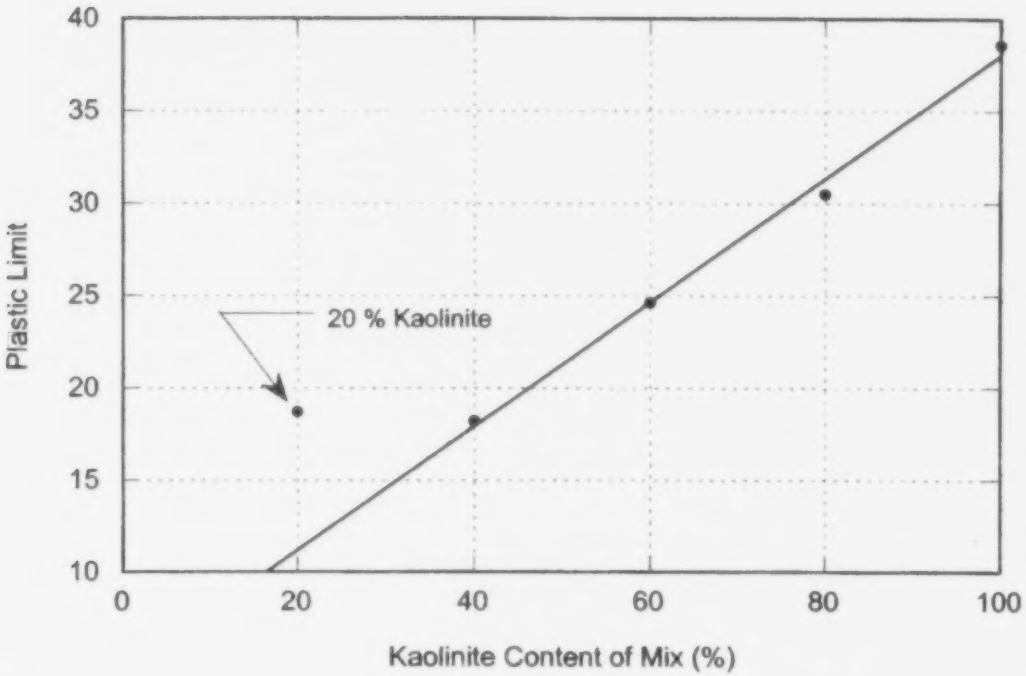


**Figure 4.5 Relationship between Plastic Limit and Kaolinite Content**

The test results shown in Figure 4.5 indicate that the sample (No. 1) with 20 % kaolinite behaves differently from the rest of the mixes. Samples No. 2 to 5 indicate a linear increase in the plastic limit with increase in the clay content. The rate of increase in plastic limit (0.34) is significantly higher (1.9 to 3.9 times) than the rates indicated by the fines from the aggregate samples.

# 5. Methylene Blue Adsorption Test Data

## 5.1 PREPARATION OF SAMPLES AND REAGENT

The fine-grained portion of the aggregate sample and the methylene blue reagent were prepared in accordance with the procedures described in AASHTO Provisional Standard TP57-99. A representative sample of the aggregate to be tested was dried to a constant mass at 110 ± 5° C and sieved through a 75µm sieve. The slurry for the test was prepared by mixing 10 grams of material finer than 75µm with 30 ml of distilled water in a 500 ml beaker. The slurry was continuously mixed using a magnetic mixer.

The methylene blue reagent used was from a fresh supply. It was stored in an amber coloured bottle and kept in a dark cabinet at laboratory temperature. One gram of methylene blue was dissolved in 200 ml of distilled water to produce a solution with a concentration of 5 mg per ml.

## 5.2 CALIBRATION AND VERIFICATION OF TEST PROCEDURE

The methylene blue adsorption test was performed on samples with known clay mineral and chemical compositions, in order to verify the MBVs obtained and to calibrate the test procedures performed in our laboratory. The MBVs were compared with those published by Verhoef (1992). The commercially available kaolin clay (china clay) and quick-gel (Wyoming sodium bentonite), which is widely used for water-based drilling fluid, were utilised for this purpose. Bentonite consists mainly of the clay mineral montmorillonite. The chemical composition and other related information for both products is given in Table 5.1.

**Table 5.1 Details of Clay Minerals Used for Calibration**

| **Trade Name** | Kaolex BN | Quick-Gel |
|---|---|---|
| **Synonyms** | Kaolin Clay or China Clay | None |
| **Chemical Composition** | Kaolinite: 94.60 - 97.20%<br>Silica (Quartz): 1.50 - 3.80%<br>Titanium Dioxide: 1.30 - 1.60% | Bentonite: 95 - 99%<br>Silica (Quartz): 1 - 5% |
| **Manufacturer** | Kentucky-Tennessee Clay Company, South Carolina, USA | Baroid Drilling Fluids, Houston, USA |

The results obtained for both products in accordance with the test procedures described in AASHTO TP57 – 99 are given in Table 5.2. For comparison purposes, the MBVs published by Verhoef (1992) for similar clay minerals are also provided in the table. The MBVs for bentonite are reasonably close to each other. The MBV published by Verhoef (1992) was

based on tests performed on samples prepared from Wyoming bentonite, which was also used in our study.

**Table 5.2 Methylene Blue Values Obtained for Known Clay Minerals**

| Clay Type | MBV (mg/g) | |
|---|---|---|
| | Obtained | Published |
| Kaolinite | 12.3 | 24 |
| Bentonite | 125.5 | 110 |

The studies published by Hang and Brindley (1970) and Verhoef (1992) suggest that when a pure clay suspension is titrated, the amount of methylene blue adsorbed in the spot test procedure would relate to the cation exchange capacity of the clay in the suspension, i.e., the flocculation point of pure clay. The clays are capable of adsorbing more methylene blue than indicated at the flocculation point. The maximum amount adsorbed is the cation exchange capacity (CEC), which depends on the chemical composition of the clay. Verhoef (1992) suggested that CEC values might vary for the same clay mineral, even if the chemical composition is identical.

## 5.3 EFFECTS OF COMPOSITION OF CLAY MINERALS ON METHYLENE BLUE VALUES

The effect of the composition of clay minerals on the adsorption capacity of methylene blue solution was investigated by mixing bentonite and kaolinite in different proportions. Four samples containing mixtures of bentonite and kaolinite were prepared. The proportions of bentonite (Quick-Gel) and kaolinite (Kaolex BN) in each sample and the methylene blue adsorption values are given in Table 5.3. The results are also provided in Figure 5.1.

**Table 5.3 Methylene Blue Values for Bentonite and Kaolinite Mixes**

| Sample No. | Bentonite (%) | Kaolinite (%) | MBV (mg/g) |
|---|---|---|---|
| 1 | 0 | 100 | 12.3 |
| 2 | 20 | 80 | 62.0 |
| 3 | 40 | 60 | 98.0 |
| 4 | 60 | 40 | 154.5 |
| 5 | 80 | 20 | 200.0 |
| 6 | 100 | 0 | 125.5 |

The test results indicate that the combination of clay minerals is capable of adsorbing more methylene blue solution than a sample containing only one type of predominant clay mineral. Sample No. 5, containing 80% of bentonite and 20% of kaolinite, adsorbed the largest volume of methylene blue (MBV of 200), i.e., 1.6 times the volume for Sample No. 6, containing

100% of bentonite. The products used do not actually contain 100 percent either bentonite or kaolinite clay minerals. As indicated in Table 5.1, both products contain varying proportions of silica (quartz). It appears that mixing produces increased cation exchange capacity. The results indicate that the MBV increases with the increase in the amount of bentonite, and the adsorption capacity depends on the type of predominant clay mineral in the mix.

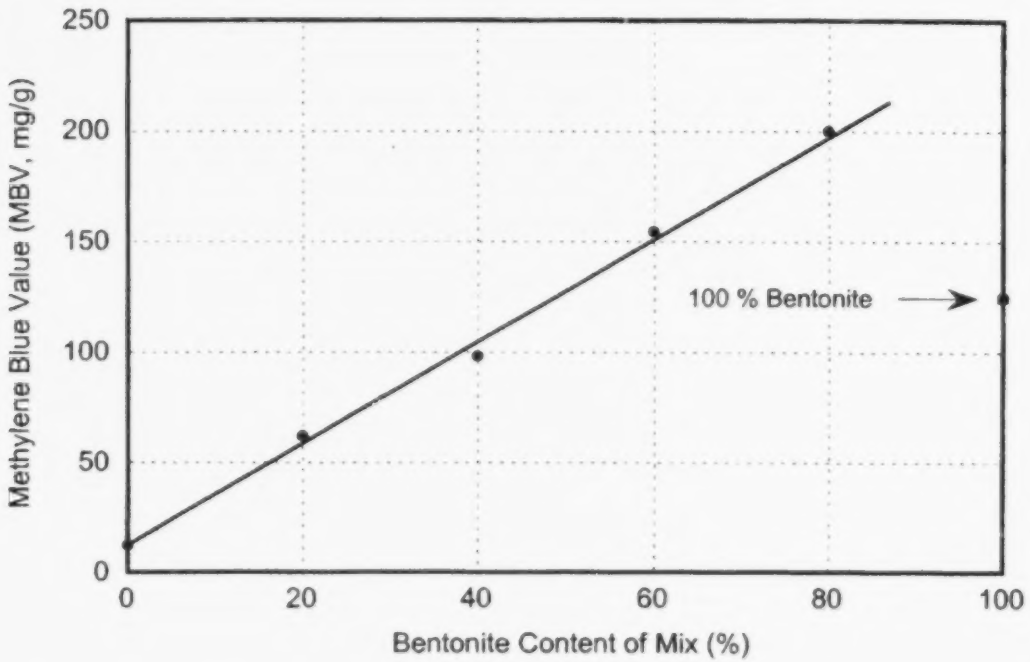


**Figure 5.1 Effects of Combined Clay Minerals on Methylene Blue Value**

## 5.4 METHYLENE BLUE ADSORPTION AND X-RAY DIFFRACTION TEST RESULTS

### 5.4.1 Aggregate Fines from Walker Vineland Quarry

The samples from all four fractions, i.e., materials finer than 425µm, 150µm, 106µm and 75µm, were tested to determine the relationship between the MBV and the percentage of clay present in the aggregate. The test results are provided in Table 5.4 and in the form of a plot in Figure 5.2. The MBVs did not vary with variation in the clay content, and the volume of methylene blue solution adsorbed remained constant irrespective of the amount of clay. It appears that the variation in clay content is too small to have any noticeable effect on the adsorption capacity. The MBVs are too low (2.0) for any known clay mineral, and may reflect the presence of other predominant minerals in the aggregate. The portion of the sample finer than 75µm was further examined by x-ray diffraction to identify the minerals present.

The x-ray diffraction test results are reported in Table 5.4 in order of decreasing abundance of minerals present in the sample. The results indicate the presence of dolomite, quartz, gypsum, calcite, albite and illite. The MBVs published by Verhoef (1992) indicate that all of the minerals that have been identified in this sample, with the exception of illite (50 to 150) and calcite (only 0.9), are inert and do not have the capacity to adsorb methylene blue solution, i.e., MBV is equal to zero.

**Table 5.4 MBV and X-Ray Diffraction Results for Vineland Quarry**

| Passing Sieve Size | % of Clay | MBV (mg/g) | Mineralogy |
|---|---|---|---|
| 425µm | 13.2 | 2.0 | Dolomite, Quartz, Gypsum, Calcite, Albite and Illite |
| 150µm | 15.0 | 2.0 | |
| 106µm | 16.1 | 2.0 | |
| 75µm | 17.4 | 2.0 | |

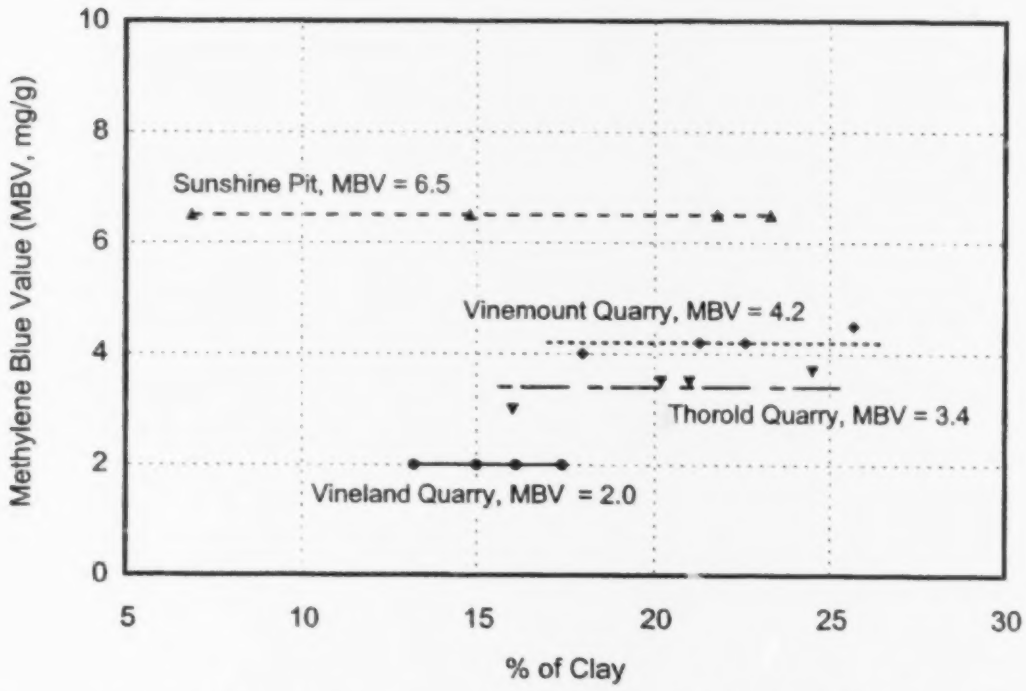


**Figure 5.2 Relationship Between Methylene Blue Value and Clay Fraction**

### 5.4.2 Aggregate Fines from Sunshine Pit

The test results for the fines from the Sunshine pit are provided in Table 5.5 and in the form of a plot in Figure 5.2. Similarly to the samples from the Vineland quarry, the MBVs did not vary with increase in the clay content, and the volume of methylene blue solution adsorbed remained constant. The MBVs are too low (6.5) to suggest any significant clay mineral in the sample, and appear to reflect the presence of other minerals in the aggregate.

The sample from the Sunshine pit was also examined by the x-ray diffraction method, and the results are presented in Table 5.5 in order of decreasing abundance. The findings indicate the presence of quartz, albite, chlorite, biotite (mica), orthoclase and hornblende. The published MBV data suggest that the minerals identified in this sample, i.e., chlorite (6.0), biotite (1.5), hornblende (1.5) and others (0), have very low potential for adsorbing methylene blue solution. The MBVs obtained appear to be reflecting the presence of chlorite (a mica like material with a layered structure similar to that of clay minerals), the third most predominant mineral, or a combination of chlorite, biotite and hornblende.

**Table 5.5 MBV and X-Ray Diffraction Results for Sunshine Pit**

| Passing Sieve Size | % of Clay | MBV (mg/g) | Mineralogy |
|---|---|---|---|
| 425µm | 6.9 | 6.5 | Quartz, Albite, Chlorite, Biotite (mica), Orthoclase and Hornblende |
| 150µm | 14.8 | 6.5 | |
| 106µm | 21.8 | 6.5 | |
| 75µm | 23.3 | 6.5 | |

### 5.4.3 Aggregate Fines from Walker Thorold Quarry

The test results are provided in Table 5.6 and in the form of a plot in Figure 5.2. The MBVs varied between 3.0 and 3.7, with an average value of 3.4. The volume of methylene blue solution adsorbed remained almost constant irrespective of the amount of clay. It appears that the variation in clay content is too small to have any noticeable effect on the adsorption capacity. The MBVs are too low to correspond to any clay mineral, and may be attributed to a combination of other minerals. The portion of the sample finer than 75µm was further examined by x-ray diffraction to identify the minerals present.

The x-ray diffraction test results are reported in Table 5.6 in order of decreasing abundance of minerals present in the sample. The results indicate the presence of dolomite, calcite, quartz, gypsum, albite and illite. The MBVs may be attributed to illite and (to a much less extent) calcite, which are the only identified minerals capable of adsorbing methylene blue solution.

**Table 5.6 MBV and X-Ray Diffraction Results for Thorold Quarry**

| Passing Sieve Size | % of Clay | MBV (mg/g) | Mineralogy |
|---|---|---|---|
| 425µm | 16.0 | 3.0 | Dolomite, Calcite, Quartz, Gypsum, Albite and Illite |
| 150µm | 20.2 | 3.5 | |
| 106µm | 21.0 | 3.5 | |
| 75µm | 24.5 | 3.7 | |

### 5.4.4 Aggregate Fines from Vinemount Quarry

The test results are provided in Table 5.7 and in the form of a plot in Figure 5.2. The MBVs varied between 4.0 and 4.5, with an average value of 4.2. The volume of methylene blue solution adsorbed remained almost constant irrespective of the amount of clay. The variation in clay content may be too small to have any noticeable effect on the adsorption capacity. The MBVs are too low to correspond to any clay mineral, and may be attributed to a combination of other minerals. Similarly to the samples from the other sites, the portion of the sample finer than 75µm was further examined by x-ray diffraction.

The x-ray diffraction test results are reported in Table 5.7 in order of decreasing abundance of minerals present in the sample. The results indicate the presence of dolomite, quartz, gypsum, albite, calcite and illite. The minerals identified in this sample are the same as those for Vineland and Thorold, but occur in a different order of abundance. The MBVs may reflect the presence of illite and (to a much lesser extent) calcite.

**Table 5.7 MBV and X-Ray Diffraction Results for Vinemount Quarry**

| Passing Sieve Size | % of Clay | MBV (mg/g) | Mineralogy |
|---|---|---|---|
| 425µm | 18.0 | 4.0 | Dolomite, Quartz, Gypsum, Albite, Calcite and Illite |
| 150µm | 21.3 | 4.2 | |
| 106µm | 22.6 | 4.2 | |
| 75µm | 25.7 | 4.5 | |

## 5.5 INFLUENCE OF CLAY CONTENT ON METHYLENE BLUE VALUE

The specific surface area of the clay mineral, which is accessible to exchange ions and other polar molecules increases with increase in clay content. As a result, the MBV is expected to increase with increase in the clay fraction. In contrast, the results of the tests on the aggregate samples indicate that the MBV depends only on the predominant mineral, and clay content of the sample has no measurable influence on the methylene blue adsorption capacity. The effect of clay content on the MBVs was further investigated by testing samples prepared by mixing commercially available crystalline silica (Ottawa quartz sand) and kaolinite (Kaolex BN) in different proportions.

The silica sand was mechanically ground passing 75μm and dried to a constant mass at 110 ± 5° C. Four samples containing mixtures of silica sand and kaolinite were prepared. The proportions of silica sand and kaolinite in each sample and the methylene blue adsorption values are given in Table 5.8. The results are also provided in the form of a plot in Figure 5.3.

**Table 5.8 Methylene Blue Values for Silica Sand and Kaolinite Mixes**

| Sample No. | Silica Sand (%) | Kaolinite (%) | MBV (mg/g) |
|---|---|---|---|
| 1 | 100 | 0 | 0.8 |
| 2 | 80 | 20 | 2.0 |
| 3 | 60 | 40 | 6.0 |
| 4 | 40 | 60 | 9.0 |
| 5 | 20 | 80 | 11.5 |
| 6 | 0 | 100 | 12.3 |

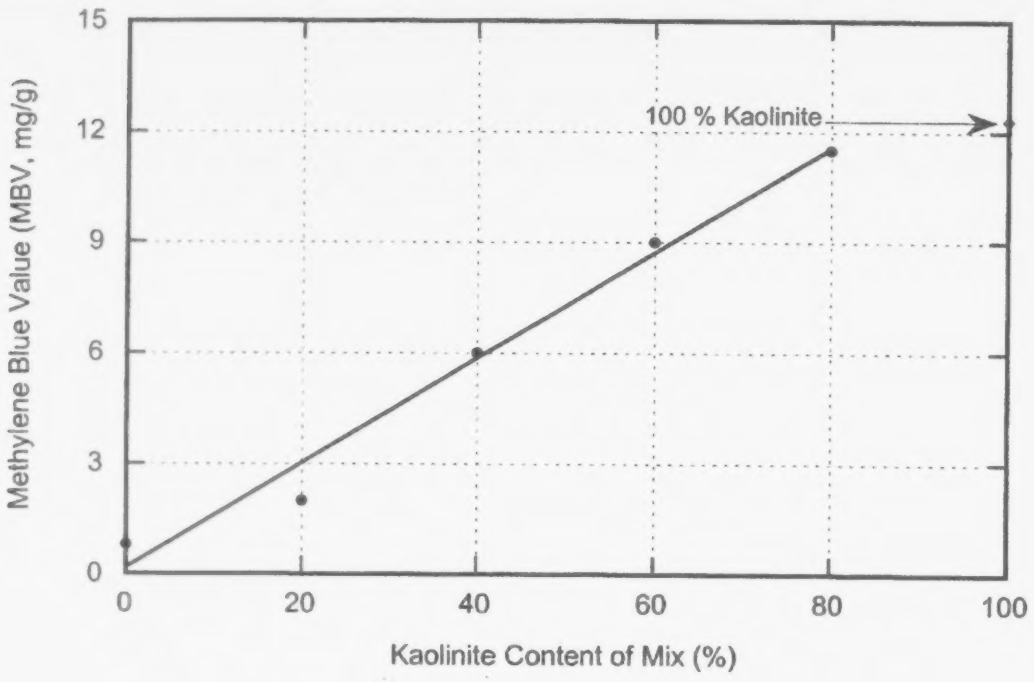


**Figure 5.3 Relationship between MBV and Kaolinite Content**

The published MBVs suggest that quartz (depending on its origin) may not have the potential to adsorb methylene blue solution. As expected, Sample No.1 (100 % silica sand) recorded a low methylene blue value (0.8 mg/g). The results for Samples No. 2 to 6 indicate an increase in the MBV with increase in the kaolinite content. The test results also suggest that a substantial (20%) increase in clay content is required to cause a noticeable increase in MBV. However, they clearly show that the MBV depends not only on the predominant clay mineral but also on the clay content and suggest that the rate of increase of MBV is substantially lower (2.6 times) than that of plastic limit (indicating less sensitivity to an increase in clay content).

# 6. Summary of Results and Discussion

## 6.1 SUMMARY OF RESULTS

The amount and type of materials finer than 75µm in an aggregate dictate engineering properties such as frost susceptibility and permeability, which in turn influence the performance of asphalt pavements. This study concentrated mainly on the properties of fines, i.e., silt and clay, that can be effectively used to qualitatively assess the aggregates. The results of plasticity index, particle size analysis, and methylene blue adsorption tests are summarised in Table 6.1. The mineralogy of aggregate fines based on x-ray diffraction tests and the clay mineralogy derived from the plasticity chart and activity value are summarised in Table 6.2, as are soil classification and average MBV. The mineralogy of the aggregate fines and the soil classifications provided in the table are based solely on the properties of aggregate samples finer than 75µm.

**Table 6.1 Summary of Index Test Results**

| Sample Source | Specific Gravity | Passing Sieve Size | Plasticity Properties | | % Clay (<2µm) | | MBV (mg/g) | Activity (A) |
|---|---|---|---|---|---|---|---|---|
| | | | Liquid Limit | Plasticity Index | Fraction | Aggregate Sample | | |
| Vineland Quarry | 2.874 | 425µm | 18.6 | 1.9 | 13.2 | 2.3 | 2.0 | 0.14 |
| | | 150µm | 20.8 | 3.9 | 15.0 | 2.2 | 2.0 | 0.26 |
| | | 106µm | 22.0 | 5.1 | 16.1 | 2.2 | 2.0 | 0.32 |
| | | 75µm | 23.6 | 6.2 | 17.4 | 2.3 | 2.0 | 0.35 |
| Sunshine Pit | 2.844 | 425µm | NP | NP | 7.8 | 1.0 | 6.5 | NP |
| | | 150µm | 27.1 | 0.6 | 14.6 | 1.1 | 6.5 | 0.04 |
| | | 106µm | 28.1 | 1.3 | 21.6 | 1.1 | 6.5 | 0.06 |
| | | 75µm | 30.9 | 3.3 | 22.5 | 1.0 | 6.5 | 0.15 |
| Thorold Quarry | 2.785 | 425µm | 18.0 | 1.8 | 16.0 | 2.4 | 3.0 | 0.11 |
| | | 150µm | 21.4 | 4.9 | 20.2 | 2.3 | 3.5 | 0.24 |
| | | 106µm | 22.3 | 5.1 | 21.0 | 2.3 | 3.5 | 0.24 |
| | | 75µm | 23.4 | 5.7 | 24.5 | 2.4 | 3.7 | 0.23 |
| Vinemount Quarry | 2.832 | 425µm | 20.2 | 3.3 | 18.0 | 1.9 | 4.0 | 0.18 |
| | | 150µm | 22.7 | 5.3 | 21.3 | 2.0 | 4.2 | 0.25 |
| | | 106µm | 22.6 | 4.9 | 22.6 | 1.9 | 4.2 | 0.22 |
| | | 75µm | 24.0 | 6.4 | 25.7 | 2.1 | 4.5 | 0.25 |

The amount of clay in each aggregate sample reported in Table 6.1 was computed from the sieve analysis results of all four fractions. The computed percentage of clay should be the same for all fractions of the aggregate sample, if the representative samples obtained by splitting are identical. However, the differences among the fractions (0.1% to 0.2%) are negligible and within the margin of experimental errors expected for this test.

**Table 6.2 Summary of Fines Characterization**

| Sample Source | Soil Classification | Clay Mineralogy | | Mineralogy | Average MBV (mg/g) |
|---|---|---|---|---|---|
| | | Plasticity Chart | Activity Value | X-Ray Diffraction | |
| Vineland Quarry | Low Plasticity Clay and Silt (CL-ML) | Located outside the area identified for minerals | Not Conclusive | Dolomite, Quartz, Gypsum, Calcite, Albite & Illite | 2.0 |
| Sunshine Pit | Low Plasticity Silt (ML) | Located outside the area identified for minerals | Not Conclusive | Quartz, Albite, Chlorite, Biotite (mica), Orthoclase & Hornblende | 6.5 |
| Thorold Quarry | Low Plasticity Clay and Silt (CL-ML) | Located outside the area identified for minerals | Not Conclusive | Dolomite, Calcite, Quartz, Gypsum, Albite & Illite | 3.4 |
| Vinemount Quarry | Low Plasticity Clay and Silt (CL-ML) | Located outside the area identified for minerals | Not Conclusive | Dolomite, Quartz, Gypsum, Albite, Calcite &Illite | 4.2 |

The suitability of the plasticity chart shown in Figure 2.2 for identifying clay minerals in aggregate fines was evaluated (Figure 6.1) even though this chart was developed for clayey soils. It is evident that the plasticity chart was not useful for the aggregates tested, although it might be useful for material that contains a substantial quantity of clay. However, it was useful to characterise the aggregate fines based on their locations on the chart.

Kaolex BN (see Table 5.1) is also plotted in Figure 6.1. The plot does not fall within the hatched area for kaolinite. The plasticity characteristics of Kaolex BN may have been influenced by other minerals present in this commercial product.

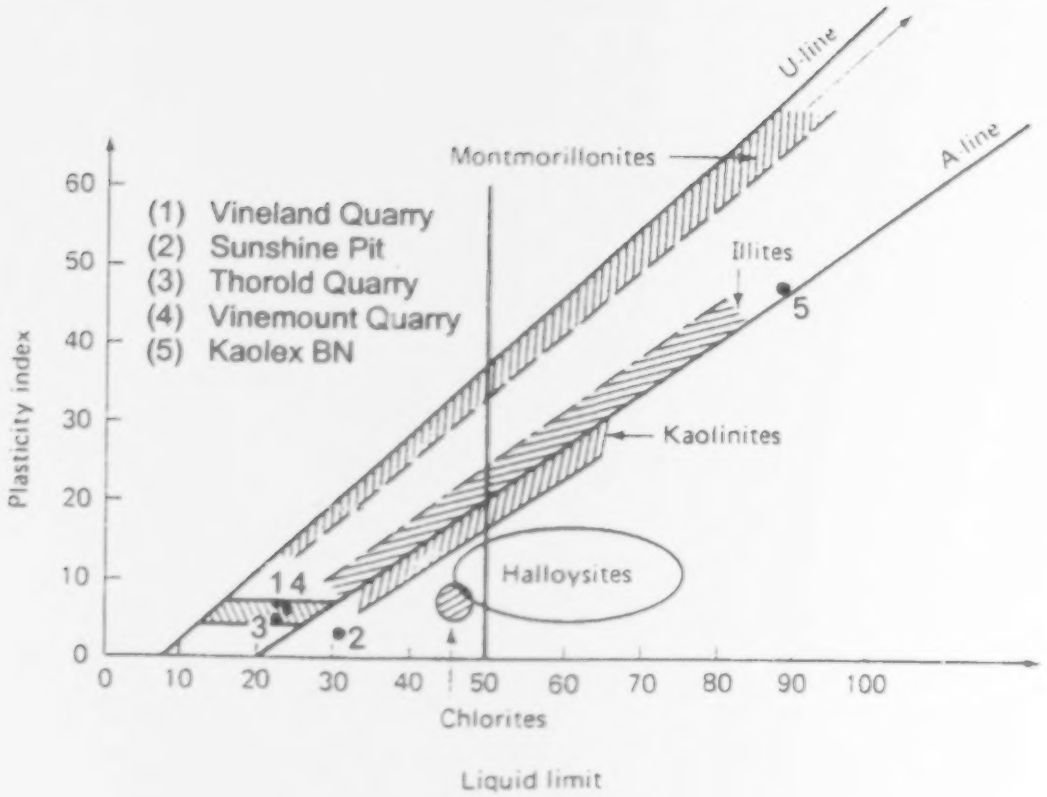


**Figure 6.1 Locations of Aggregate Fines on Plasticity Chart**

## 6.2 ASSESSMENT OF AGGREGATES BY PLASTICITY INDEX

Figure 6.2 provides a correlation between the plasticity index and the amount of clay present in the samples, and compares the activity of aggregate fines from the four sites. The activity of the sample mass depends on the amount of adsorbed water, which is largely influenced by the amount of clay that is present in the sample. It is clear from the plot that the sample from the Vineland quarry (1) contains the highest amount of clay and that from the Sunshine pit (2) contains the lowest.

Theoretically, the plasticity index versus clay content plot is expected to pass through the origin (0,0) for clayey soils (Skempton, 1953). In the case of aggregate fines the plot may not pass through the origin, because the clay present in the sample may not be active enough to influence the behaviour of the sample mass. The plots for all four sites in Figure 6.2 intercept the abscissa, i.e., PI = 0, at clay contents ranging from 9.1% (Vinemount quarry) to 13.0% (Sunshine pit). The Atterberg limits are based on the concept that the clayey soils can exist in solid, semi-solid, plastic and liquid states. This concept is not applicable to aggregate fines,

which are classified as low plasticity clay and silt (Table 6.2).

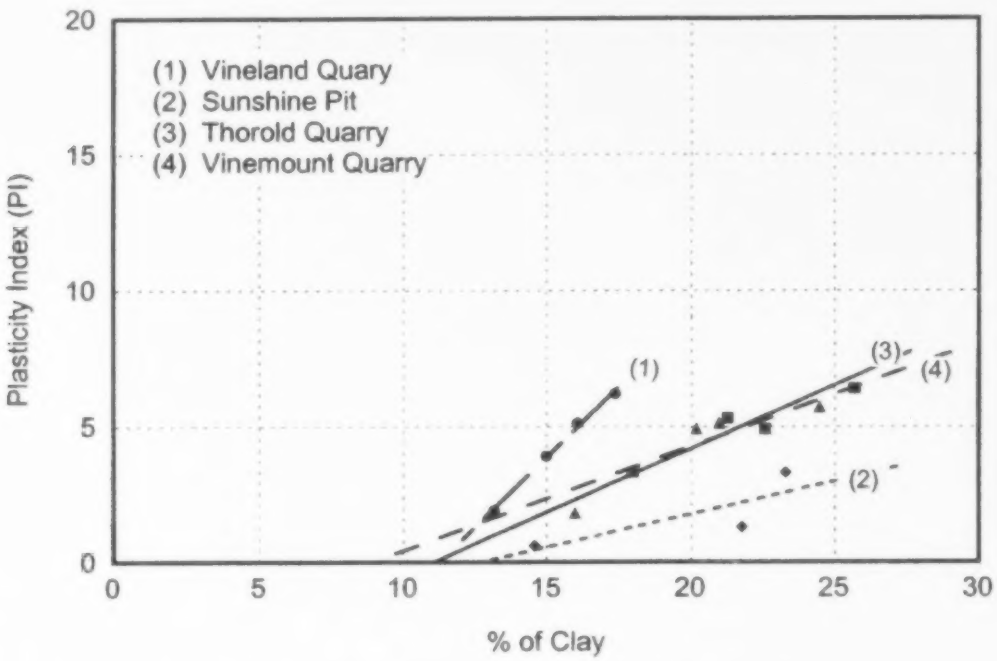


**Figure 6.2 Relationship Between Plasticity Index and Clay Fraction**

The plasticity index can be zero only when the liquid limit is equal to the plastic limit and the PI = 0 requirement specified in MTO standards for granular base and sub-base cannot be established from the Atterberg limit test alone. The Atterberg limits are an indication of the upper and lower limits of the plasticity of soils, and provide only a qualitative assessment of the aggregate fines, i.e., plastic or non plastic. For a qualitative assessment of the aggregate, the plastic nature of the aggregate fines could be easily determined from a plastic limit test alone without carrying out the liquid limit test, which requires considerable skill and equipment. The test is preferably performed on material passing the 75 μm sieve for a positive identification of clays in aggregate.

## 6.3 EFFECT OF CLAY CONTENT ON ATTERBERG LIMITS AND METHYLENE BLUE ADSORPTION

The results from hydrometer, Atterberg limit and methylene blue adsorption tests were further examined to study the sensitivity of these index properties to the change in clay content (Table 6.3). The specific surface area accessible to water and other polar molecules increases with an increase in the amount of clay. As a result, the liquid limit and plastic limit are expected to increase with an increase in clay content. This was found to be true only for the liquid limit.

The results for the four sites indicate a significantly higher rate of increase in liquid limit (0.35 to 1.18) compared to that in plastic limit (0.09 to 0.18). The sample from the Vineland quarry, with the highest activity values, shows the highest rate of increase in liquid limit, and the lowest rate of increase is associated with the sample from the Sunshine pit.

The response of the plastic limit to an increase in the amount of clay was further examined by testing mixes of Ottawa sand and kaolinite. The test results indicate a rate of increase of 0.34, which is 2 to 3 times higher than for aggregate fines (0.09 to 0.18). It appears that an increase in clay content influences the plastic limit to a lesser degree than the liquid limit, and the response is further reduced when the sample is deficient in clay minerals. The aggregate samples finer than 425 µm from the four sites contain 7.8 % to 18.0 % of clay-sized particles and those passing the 75 µm sieve contain 17.4 % to 25.7 % (Table 6.1). For a qualitative assessment, material finer than 75 µm may provide a better representation of the presence of clay in aggregate. For this reason, when evaluating granular base aggregates, the plastic limit is preferably determined from material finer than 75 µm.

**Table 6.3 Influence of Clay Fraction on Atterberg Limits and MBV**

| Sample Source | Rate of Increase in Limits & MBV/Percent of Clay | | | |
|---|---|---|---|---|
| | Liquid Limit | Plastic Limit | MBV | Ratio (LL/PL) |
| Vineland Quarry | 1.18 | 0.15 | 0.0 | 7.8 |
| Sunshine Pit | 0.35 | 0.10 | 0.0 | 3.5 |
| Thorold Quarry | 0.65 | 0.18 | 0.0 | 3.6 |
| Vinemount Quarry | 0.48 | 0.09 | 0.0 | 5.0 |
| Sand/Kaolinite | - | 0.34 | 0.14 | 2.6 (PL/MBV) |
| Bentonite/Kaolinite | - | - | 2.37 | |

Similarly to the Atterberg limits, the methylene blue adsorption values were expected to increase with an increase in the clay content. This was found not to be true for the aggregate fines tested, the values remaining almost constant for all four fractions. The response of methylene blue adsorption to an increase in the amount of clay was further investigated using the Ottawa sand/kaolinite mix combinations that were used for plastic limit tests. The rate of increase was only 0.14 per cent increase in the amount of clay, which is 2.6 times lower than that of plastic limit. However, a rate of increase of 2.37 was noted for the bentonite/kaolinite mix combinations. This rate of increase is almost 17 times higher than that of the sand/kaolinite combination, and is attributed to the fact that bentonite contains the active clay mineral montmorillonite. It is clear from the test results that the methylene blue adsorption value depends mainly on the predominant minerals in the sample. In the case of aggregates, non-clay minerals are predominant in material finer than 75 µm. Based on the test results, the possibility of detecting the presence of clay in aggregate fines by the methylene blue adsorption method is remote to non-existent.

## 6.4 REVIEW OF CURRENT SPECIFICATIONS IN RELATION TO THE TEST RESULTS

The MTO granular base and sub-base (OPSS 1010) requirement is that the finer portion of aggregate must be non-plastic as determined in accordance with MTO LS - 703 and 704. The specification is based on the liquid and plastic limits determined from material that is finer than 425 μm and dried at 110 ± 5° C. In this study, the aggregates were dried at room temperature to minimize the drying effect on the fine-grained portion of the aggregate. The plasticity indexes determined for all four fractions for three of the four sites, i.e., Vineland, Thorold and Vinemount, are higher than zero (PI >0) and do not meet the specification requirement. In the case of the Sunshine pit, three of the four fractions (passing 150μm, 106μm and 75μm) had a plasticity index value higher than zero. None of the tested samples meet the specification, if the aggregates are assessed based on the plasticity index of materials finer than 150 μm. The test results demonstrate that the plasticity of the aggregate fines heavily depends on the fraction of the material on which the test was performed to determine the Atterberg limits.

The plasticity index basically indicates the plastic range, or the range of water content within which the fine-grained material possesses plasticity. In the case of aggregates, both plasticity index and plastic limit provide only a qualitative assessment of the aggregate. A hydrometer analysis is required for the quantitative determination of clay-sized particles, i.e., particles finer than 2μm. This test procedure is time consuming and requires equipment and a skilled technician to perform. A qualitative assessment of the aggregates for presence of clay could be made from the plastic limit test alone. The plasticity index required by OPSS 1010 does not provide any additional information to assess the aggregate. A complete Atterberg limit test is not required to assess the aggregates for the presence of clays, and OPSS 1010 may be amended to employ the plastic limit test alone.

The methylene blue adsorption values of the tested aggregates range from 2.0 to 6.5. These values are within the range of MBVs provided in AASHTO TP57 for aggregates that are expected to perform excellently when used in hot mix asphalt paving mixes. Based on these MBVs, the aggregates from all four sites are not only acceptable but also expected to perform excellently. The Ottawa sand and kaolinite mixes with 20 % and 40 % kaolinite clay that were used in this study recorded MBVs of 2.0 and 6.0, respectively. The methylene blue adsorption tests on the mixes with 60 % and 80 % kaolinite resulted in MBVs of 9.0 and 11.5, respectively. This suggests that aggregate fines (material finer than 75 μm) with 20 to 40 % of kaolinite are not only acceptable for hot mix asphalt, but also expected to perform excellently. Further, the fines with 60 to 80 % of kaolinite are marginally acceptable. The proportions of kaolinite and Ottawa sand mix (20% to 80%) used in this study are similar to permitting 2% to 8% of kaolinite in the MTO specification for quarried Granular 'A'. We think it is unlikely that the aggregate with 2% to 8% of kaolinite will be acceptable for asphalt hot mix or granular base of a pavement structure.

The relationship between the methylene blue value and the expected performance of hot mix

asphalt pavements provided by AASHTO TP 57 and Kandhal et al. (1998) is with respect to the properties of the asphalt mixes. The results of x-ray diffraction and methylene blue adsorption tests from this study suggest that MBVs less than six may result from non-clay minerals or a combination of inactive clay and non-clay minerals, which commonly occur in aggregate fines. The MBV, especially when it is lower than about six, may not be an indication of harmful clays. AASHTO TP57 may have been intended for asphalt mixes, but the scope of the test method states that the standard provides procedures for determining the amount of potential harmful fine material including clay and organics present in an aggregate. The test method does not provide any means to calculate the amount of harmful clays in aggregates. ASTM C 837 – 99, which is slightly different from AASHTO TP57, on the other hand recommends the methylene blue adsorption value as an index test for presence of clay. In light of the results from this study, the use of both AASHTO TP57 and ASTM C 837 to determine the presence of relatively small amounts of clay in aggregates has to be questioned.

A comparison of plastic limit and methylene blue test results indicates that the plastic limit is more responsive to minor variation in the amount of clay than the methylene blue adsorption value. The MBVs remained almost constant for all the aggregate samples tested. The samples from three of the four sites as well as the Ottawa sand/kaolinite mixes that were studied do not meet the requirements of OPSS 1010, but all of these samples would be acceptable by the AASHTO standard. The results indicate that the plastic limit test is the most effective means to qualitatively assess the aggregates for the presence of clay. For this reason, it is recommended that the plastic limit determined from material finer than 75μm be used to assess aggregate for presence of clay.

# 7. Conclusions

- The Atterberg limit test that was developed for soils may not be effective as is to qualitatively assess aggregates for presence of harmful clays.

- The dry sample preparation procedure described in MTO LS-600 may destroy the plastic properties of the aggregate fines, i.e., material finer than 75μm. The test should be performed on material finer than 75μm obtained by the wet preparation method or from the sample that was preserved in its natural state, if harmful clays in aggregates are to be determined positively.

- If plasticity index is to be specified as one of the requirements in OPSS 1010, the specification should be amended.

- The liquid limit and plasticity index are significantly influenced by the amount of clay, but the clay content has only a marginal influence on the plastic limit in the aggregate fines studied.

- Plastic limit test results obtained from material finer than 75 μm provide sufficient information to positively identify presence of clay and are alone adequate to confirm the presence of plastic fines or clay in aggregates.

- The plastic limit test method has the advantages that it is quick to perform, it requires very simple auxiliary equipment, and the operator skills needed to perform the test are minimal.

- Activity value and plasticity chart are not useful for identification of clay minerals in aggregate fines.

- The methylene blue adsorption value of the aggregate fines depends mainly on the predominant mineral or combination of minerals present in the aggregate.

- Methylene blue value is not sensitive to small variations in the amount of clay and does not provide information for positive identification of clay unless the fines contain substantial quantities of a particular clay mineral. This test method may not be effective to determine the harmful clays in aggregates.

- The relationship between methylene blue value and the performance of hot mix asphalt pavement published by AASHTO is questionable.

# 8. Recommendations

The methylene blue adsorption value was not sensitive to presence of clay or variations in clay content in Ontario aggregates studied. This test method is not recommended for qualitative assessment of aggregates for presence of clay.

Instead of specifying a plasticity index, it is sufficient to measure plastic limit alone to determine the presence of clay in aggregate fines. The plastic limit test is a shorter test procedure and has the advantages that it is quick to perform, it requires very simple auxiliary equipment, the operator needs minimal training, the test can be performed in the field, and a formal laboratory set up is not required. A modified version of the plastic limit test is recommended for identifying the presence of clay in aggregates and the test procedure is appended to this report.

It is recommended that OPSS 1010 be amended to reflect the proposed changes to the test procedure.

# 9. Acknowledgements

The authors wish to acknowledge the assistance and dedicated work of the laboratory staff of the Soils and Aggregates Section in preparation of samples and performing the tests. In particular, the dedicated work and efforts of Peter Corsaro and Julia Gabriele are gratefully acknowledged. Bob Gorman was responsible for identifying the aggregate sources and collection of the samples used in this study. His assistance and efforts are gratefully acknowledged.

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# Appendix A: Proposed Test Method

**Title: METHOD OF TEST FOR QUALITATIVE DETERMINATION OF PRESENCE OF CLAY IN AGGREGATES**

## 1. SCOPE

1.1 This method covers the procedure for qualitative determination of the presence of potentially harmful plastic fines or active clay particles in aggregates.

## 2. RELEVANT DOCUMENTS

2.1 ASTM D 4318

2.2 ASTM E 11

2.3 AASHTO T 89

## 3. SIGNIFICANCE AND USE

3.1 The plastic limit is the water content at which the fine-grained material begins to crumble when rolled out into a 3.2 mm diameter thread. If the test specimen prepared by this method can be rolled into a 3.2 mm diameter thread, it indicates the presence of potentially harmful clay or plastic fines in the sample.

3.2 This test procedure may be used as an integral part of the material specification to qualitatively assess the presence of harmful clays in aggregate fines.

3.3 The plastic property, i.e., liquid limit and plastic limit, of clay and materials containing a substantial amount of organic impurities decreases dramatically when the sample is oven-dried before testing. Comparison of the results before and after oven drying can be used as a qualitative measure of organic matter content in the aggregate sample.

## 4. APPARATUS

4.1 Ground Glass Plate: A 300 mm x 300 mm ground glass plate for rolling plastic limit threads.

4.2 Sieves: 200 mm diameter, 75 μm (No. 200) and 2.00 mm (No. 10) sieves conforming to the requirements of ASTM Specification E 11.

4.3 Spatula: A 20 mm wide, 100 mm to 125 mm long spatula.

4.4 Storage Container: A porcelain, glass or plastic container that will not contaminate the specimen in any way and that will prevent moisture loss, to store the prepared test specimen.

4.5 Wash Bottle: A wash bottle or similar container for adding controlled amounts of water to the sample and washing fines from the coarse particles.

4.6 Washing Pan: A clean flat-bottomed pan slightly larger than the 200 mm diameter sieves.

4.7 Water: Potable water.

## 5. SAMPLE PREPARATION

5.1 Samples may be taken from any location that satisfies the testing needs. Samples shall be kept at their natural moisture content.

*Note 1: Clays of certain geologic origin or materials containing a substantial amount of organic impurities will lose their plastic property when oven-dried. For this reason, the samples should not be dried before testing.*

5.2 Obtain a representative portion from the total sample sufficient to provide 20 to 30 g of material passing the 75 µm (No. 200) sieve.

5.3 Place the selected sample in a pan or dish and add a sufficient quantity of water to cover the material. Soak until all lumps have softened and the fines no longer adhere to the surfaces of the coarse particles.

*Note 2: In some cases, the cations of salts present in tap water will exchange with the natural cations in the fines from the aggregate and significantly alter the test results if tap water is used in the soaking and washing operations. As a general rule, water containing more than 100 mg/L of dissolved solids is not suitable for washing or soaking operations.*

5.4 Place the 75 µm (No. 200) sieve in the bottom of the pan. Pour the aggregate-water mixture over a 2.00 mm (No. 10) sieve nested above the 75 µm sieve, and rinse the coarse particles with a small quantity of water from a wash bottle.

5.5 After washing and removing the coarse particles, agitate the slurry on the No. 10 sieve by stirring with the fingers. Break the soil lumps or clay balls that have not slaked into individual particles by gently rubbing them over the sieve with the fingertips. Discard all the materials retained on the No. 10 and No. 200 sieves after obtaining adequate material.

5.6 Reduce the moisture content of the material passing the 75 μm (No. 200) sieve by exposing it to air currents at room temperature, or to warm air currents from a source such as an electric hair dryer, to a consistency at which it can be rolled without sticking to the hands.

*Note 3: It is important that the material not be dried.*

## 6. TEST PROCEDURE

6.1 Select approximately 6 g from the sample prepared in accordance with Section 5, and form the selected portion into an ellipsoidal mass.

6.2 Roll the mass between the palm or fingers and the ground glass plate with just sufficient pressure to roll it into a thread of uniform diameter throughout its length. Roll the mass until it reaches 3.2 mm in diameter. The rolling should not take more than 2 minutes.

*Note 4: A normal rate of rolling for most fine- grained materials should be 80 to 90 strokes per minute. Count a stroke as one complete motion of the hand forward and back to the starting position. The rate of rolling may have to be decreased for very fragile materials.*

*Note 5: A 3.2 mm diameter rod is useful for frequent comparison with the thread to ascertain whether it has reached the proper diameter.*

6.3 Break the thread into several pieces when the diameter of the thread becomes 3.2 mm. Squeeze the pieces together, knead between the palm and first finger, reform into an ellipsoidal mass, and re-roll. Repeat this process until the thread crumbles under the pressure required for rolling and the mass can no longer be rolled into a 3.2 mm diameter thread.

6.4 The thread will break into shorter pieces. Roll each of the shorter pieces to 3.2 mm diameter threads. Continue the test until the threads can be reformed into an ellipsoidal mass and rolled out again. The operator shall not attempt to produce failure at exactly 3.2 mm diameter by allowing the thread to reach 3.2 mm and then reducing the rate of rolling, or pressure, or both. If the sample cannot be reformed and rolled out again it is non-plastic and the testing ends here.

6.5 A satisfactory end point is considered to have been reached if crumbling occurs when the thread has a diameter greater than 3.2 mm, provided that the mass has been previously rolled into a thread 3.2 mm in diameter.

6.6 When crumbling occurs, select another approximately 2g portion from the original 20 to 30 g mass and repeat the process described in 6.2 to 6.5.

## 7. REPORT

7.1 If the plastic limit test could not be performed as described above, report that the fines from the aggregate are non-plastic (NP).

7.2 If the plastic limit test could be performed, report that the sample contains plastic fines.

# Appendix B: Test Records

**TEST REPORT – INDEX PROPERTIES**

| Project: Test Method Development | | | | W.O. No.: N/A | | | | Borehole No: N/A | | | | Ground Elevation: N/A | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Client Name: Mark Vasavithasan | | | | Address: Room 220, Building C, Soils & Aggregate Section | | | | | | | | Telephone: (416) 235 - 4901 | | | | | |
| Sample Data | | | | W | Atterberg Limits | | | Unit Weight (t/m$^3$) | | $S_G$ | Grain Size Distribution (%) | | | | | MBV (mg/g) | MTO Soil Symbol |
| Field No. | Depth | Lab No. | Type | % | $W_L$ | $W_P$ | $I_P$ | $\gamma_b$ | $\gamma_d$ | | Gravel | Sand | Silt | Clay | | | |
| 00-VM-9005 | N/A | 00B-9007 | 425µm | - | NP | NP | NP | - | - | 2.844 | - | 48.5 | 43.7 | 7.8 | | 6.5 | ML |
| | | | 150µm | - | 27.1 | 26.5 | 0.6 | - | - | - | - | 16.4 | 69.0 | 14.6 | | 6.5 | ML |
| | | | 106µm | - | 28.1 | 26.8 | 1.3 | - | - | - | - | 4.7 | 73.7 | 21.6 | | 6.5 | ML |
| | | | 75µm | - | 30.9 | 27.6 | 3.3 | - | - | - | - | 0.0 | 77.5 | 22.5 | | 6.5 | ML |
| 00-VM-9008 | N/A | 00B-9009 | 425µm | - | 18.6 | 16.7 | 1.9 | - | - | 2.874 | - | 23.7 | 63.1 | 13.2 | | 2.0 | ML |
| | | | 150µm | - | 20.8 | 16.9 | 3.9 | - | - | - | - | 10.5 | 74.5 | 15.0 | | 2.0 | ML |
| | | | 106µm | - | 22.0 | 16.9 | 5.1 | - | - | - | - | 3.8 | 80.1 | 16.1 | | 2.0 | CL - ML |
| | | | 75µm | - | 23.6 | 17.4 | 6.2 | - | - | - | - | 0.0 | 82.6 | 17.4 | | 2.0 | CL - ML |

All Known Deviations from Test Method: None

Comments: The tests were done only on the aggregate samples finer than 425µm, 150µm, 106µm & 75µm sieves to determine the plasticity characteristics and the methylene blue adsorption capacity. Methylene blue adsorption test was performed according to AASHTO TP57. Samples were prepared by drying at room temperature.

W – Moisture Content
$W_L$ – Liquid Limit
$W_P$ – Plastic Limit
$I_P$ – Plasticity Index
$\gamma_b$ – Bulk Unit Weight
$\gamma_d$ – Dry Unit Weight
$S_G$ – Specific Gravity

Tested by: Julia Gabriele and Peter Corsaro | Checked by: Peter Corsaro

Reviewed by: Peter Corsaro | Signature: | Date:

**TEST REPORT – INDEX PROPERTIES**

| Project: Test Method Development | W.O. No.: N/A | Borehole No: N/A | Ground Elevation: N/A |
|---|---|---|---|
| Client Name: Mark Vasavithasan | Address: Room 220, Building C, Soils & Aggregate Section | | Telephone: (416) 235 - 4901 |

| Sample Data | | | | W | Atterberg Limits | | | Unit Weight ($t/m^3$) | | $S_G$ | Grain Size Distribution (%) | | | | MBV (mg/g) | MTO Soil Symbol |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field No. | Depth | Lab No. | Type | % | $W_L$ | $W_P$ | $I_P$ | $\gamma_b$ | $\gamma_d$ | | Gravel | Sand | Silt | Clay | | |
| 00-VM-9009 | N/A | 00B-9010 | 425µm | - | 18.0 | 16.2 | 1.8 | - | - | 2.785 | - | 0.0 | 84.0 | 16.0 | 3.0 | ML |
| | | | 150µm | - | 21.4 | 16.5 | 4.9 | - | - | | - | 0.0 | 79.8 | 20.2 | 3.5 | CL - ML |
| | | | 106µm | - | 22.3 | 17.2 | 5.1 | - | - | | - | 0.0 | 79.0 | 21.0 | 3.5 | CL – ML |
| | | | 75µm | - | 23.4 | 17.7 | 5.7 | - | - | | - | 0.0 | 75.5 | 24.5 | 3.7 | CL - ML |
| 00-VM-9010 | N/A | 00B-9011 | 425µm | - | 20.2 | 16.9 | 3.3 | - | - | - | - | 0.0 | 82.0 | 18.0 | 4.0 | ML |
| | | | 150µm | - | 22.7 | 17.4 | 5.3 | - | - | - | - | 0.0 | 78.7 | 21.3 | 4.2 | CL - ML |
| | | | 106µm | - | 22.6 | 17.7 | 4.9 | - | - | 2.832 | - | 0.0 | 77.4 | 22.6 | 4.2 | CL - ML |
| | | | 75µm | - | 24.0 | 17.6 | 6.4 | - | - | - | - | 0.0 | 74.3 | 25.7 | 4.5 | CL - ML |

All Known Deviations from Test Method: None

Comments: The tests were done only on the aggregate samples finer than 425µm, 150µm, 106µm & 75µm sieves to determine the plasticity characteristics and the methylene blue adsorption capacity. Methylene blue adsorption test was performed according to AASHTO TP57. Samples were prepared by drying at room temperature.

W – Moisture Content
$W_L$ – Liquid Limit
$W_P$ – Plastic Limit
$I_P$ – Plasticity Index
$\gamma_b$ – Bulk Unit Weight
$\gamma_d$ – Dry Unit Weight
$S_G$ – Specific Gravity

| Tested by: Julia Gabriele and Peter Corsaro | Checked by: Peter Corsaro | |
|---|---|---|
| Reviewed by: Peter Corsaro | Signature: | Date: |